ARTICLE IN PRESS

Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Optimization of machining parameters in wire EDM of OFHC copper using Taguchi analysis

P. Satishkumar [a,*], C. Saravana Murthi [b], R. Meenakshi [a]

[a] Department of Mechanical Engineering, Karpagam Institute of Technology, Coimbatore, Tamilnadu, India
[b] Department of Mechanical Engineering, United Institute of Technology, Coimbatore, Tamilnadu, India

ARTICLE INFO

Article history:
Received 16 May 2020
Accepted 6 June 2020
Available online xxxx

Keywords:
Wire EDM
Copper
Taguchi
Anova
MRR
Ra

ABSTRACT

WEDM may endure a one among the non-traditional machining processes used for machining advanced form parts and onerous materials like composites and inter-metallic materials. This paper emphasizes the study of unique variance in optimal solutions likely, metal removal rate and surface roughness based on the process parameters of wire electric arc machining in OFHC copper machining. Mathematical models are progressively developed for metal removal rates and surface roughness mistreatment Taguchi constant styles (L9) and consequently opted for improvement in objective functions. In key addition, the logistic regression equations were developed jointly between the process variables because the constant impact on metal removal rates and surface roughness are merely opposite, potential downside is adequately considered as a multi-objective improvement problem. The solutions obtained therefore may be utilized as machining recommendations to line levels of method parameters to satisfy the set of said method yield criteria. Over here, results indicate precisely that pulse on time is the most vital issue influencing the MRR and Ra followed by pulse off time and wire tension.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Trends and Innovation in Mechanical Engineering: Materials Science.

1. Introduction

Wire discharge machining is one of all the non-traditional machining processes used in small-scale machining sector to manufacture terribly complicated micro merchandise, such as shaping dies, plastic molds, punches and contour cutting, etc., from laborious materials that measure square hard to machine. During material cutting, the process creates low residual stresses as it does not require higher tool wear during material removal culminating in a minimal variation in the workpiece material during machining. Electrical discharge machining (EDM) is a non-traditional, thermo electrical process that dissolves work piece through a series of discreet sparks between the workpiece and the tool conductor is immersed within the liquid insulator medium.

Some electrical discharges soften and vaporize minute quantities of the working material, which is then expelled by the insulator and flushed away. An EDM wire produces spark discharges between a small wire conductor and a piece of de-ionized water as the insulating medium and the erodes and work piece have advanced two- and three-dimensional forms in line with a numerically controlled (NC) path. The key goals of WEDM makers and users are to achieve the WEDM method's much better stability and productivity. As new and additional exotic materials are produced and additional complicated shapes are provided, traditional machining operations still meet their limits and hence the increased use of WEDM in manufacturing continues to increase at the associated accelerated rate. Wire electrical discharge machining suppliers and consumers, promote the attainment of greater machining efficiency with the desired quality and surface quality.

In WEDM, system variables affecting performance measurement material removal rate and work piece surface roughness square calculate discharge current, discharge power, pulse length, pulse frequency, wire velocity, wire tension, average operating voltage, etc. A range of different of researchers have worked on WEDM to investigate the effect of variables on responses by many materials Selvakumar et al.2014 investigated the copper alloy experimental work and multi-objective development of Wire discharge machining (WEDM). The Taguchi experimental style methodology was supported by a series of experiments which considered pulse-on time, pulse-off time, peak current and wire

---

* Corresponding author.
E-mail address: sp.sathishkumar10@gmail.com (P. Satishkumar).

https://doi.org/10.1016/j.matpr.2020.06.120
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Trends and Innovation in Mechanical Engineering: Materials Science.

Please cite this article as: P. Satishkumar, C. Saravana Murthi and R. Meenakshi, Optimization of machining parameters in wire EDM of OFHC copper using Taguchi analysis, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.06.120

tension as input parameters. ANOVA experiment of cutting speed and surface roughness was conducted to assess the degree of importance of the parameters. The study of the signal-to-noise ratio obtained an optimal combination of the parameters for the minimum surface roughness and the maximum cutting speed. Dhakad et al. calculated the factors influencing the entire surface are acquired taking parameters such as CS, TON, TOFF and PC. Parameters need to be improved to achieve the greatest surface finish for specific MMC compositions. Quintal Maji and Dilip Kumar Pratihar pursued model knowledge of an electrical discharge machining operation using additional experimental record-dependent regression assessment. For this imitation, parameters were viewed with top current, pulse-on-time and pulse-off time and two yields, precisely the material removal rate (MRR) and surface roughness (SR).

Martowibowo et al. Carried out experiments to significantly improve Wire EDM system input parameters including no load voltage, condenser, on-time, off-time, and wire speed, for medium carbon steel machining ASSAB 760. The analysis indicates that the on-time angle and the taper angle, respectively, which strongly influence the MRR and the SR.. This article examines the design of WEDM process variables utilizing Taguchi technique as well as the effect of process parameters on a response through ANOVA analysis. Statistical analysis program MINITAB 15 has been used in the present research to design experiments and to carry out ANOVA analysis.

2. Methodology

2.1. Taguchi method

In current traditional metal removal techniques, machining of electrically conductive materials from MMCs of specific hardness is very tough process WEDM is one of the unconventional machining techniques used only to resolve the above mentioned problem. In this process, the surface finish obtained is mainly determined by different process parameters such as TON, TOFF, CS and PC. The parameters should be adjusted for different composition of MMCs to achieve the maximal surface finish. By considering all stages of process parameters, it is boring and costly to perform experiments. To get optimum process parameters, an experimental technique and a mathematical model are required. In this process, the analytical data are transmitted to the signal-to-noise ratio SN ratio), is an approximation of the output characteristics and follows the measure of lower the better (LtB), normal the better (NtB) and higher the better (HtB) forms as follows (1)-(3) in equations.

LtB S/N Ratio:

$$\eta = -10\log_{10}\frac{1}{n}\sum_{k=1}^{n} y_k^2 \tag{1}$$

NtB S/N Ratio:

$$\eta = -10\log_{10}\frac{\mu^2}{\sigma^2} \tag{2}$$

HtB S/N Ratio:

$$\eta = -10\log_{10}\frac{1}{n}\sum_{k=1}^{n}\frac{1}{y_k^2} \tag{3}$$

where,

y_i- Response value of i^{th} run, μ- Mean value, σ- Standard deviation, n- Number of run,η- S/N Ratio and k- Index fora number of runs

The technique has been developed in three stages by drawing the process variable for refinement to improve the surface finish with copper. During the first step, Taguchi's analysis of variance (L9) is used to perform experiments for the sample with different rates of input parameters and determine the corresponding surface finish.In a second phase, the variable which affects surface finish is calculated separately for the sample using ANOVA. In the third stage, confirmation experiments confirmed that the optimization process variables are obtained using ANOVA by MINITAB 15.

2.2. Selection of process parameters

Three parameters are listed in this paper, namely TON, TOFF and WF with three grades, and the details are shown in Table 1, Taguchi's L9 Orthogonal Array was selected to perform the experiments shown in Table 2. Since the solution is surface roughness, measuring the S / N ratio is considered to be less of the better quality attribute. The control variables are here: A, B, and C are Control factors. Variable outcomes were evaluated using MINITAB 15, Taguchi method, statistical analysis, and ANOVA assessment. The trials were performed based on the settings shown in the orthogonal series.

2.3. Experimental setup

The tests were conducted on the MITUTOYO SPRINTCUT WEDM unit shown in Fig. 1. This is a 3-axis automated multi-process integrated machining system for the execution of different machining operations. Wire EDM was a very complicated method consisting of complex interactions with a wide number of factors, such as machine devices, workpiece tools and processing parameters. OHFC copper bits of size 100 × 25 × 10 mm, are cut into length with a depth of 12 mm for a longer length. A 0.25 mm diameter stratified wire (zinc coated copper wire) with vertical orientation has been used and discarded once used. The test specimen to be manufactured is placed on the table controlled by a processing unit. A very tiny hole is post-drilled throughout the workpiece, from which a rather thin wire chrome plated brass/ molybdenum is threaded, so this wire is powered by a feed rate mechanism. The dielectric fluid (distilled water) is pumped through the workpiece and the wire (tool). When D.C supply is provided with a circuit, the spark will be generated all across the gap between both the wire and the workpiece. The chemical properties of copper metal have been tested and the amount of the elements is shown in Table 3.

Once the voltage over the gap is sufficiently high, a high-powered spark is obtained. This spark takes place at a range of 10 to 30 microseconds. So there are thousands of spark discharges per second around the very narrow gap between both the wire and also the workpiece, which causes the temperature to rise. At a high pressure and temperature, metal workpiece is cooled, eroded, and most of it is evaporated. In this way, the metal is separated again from a workpiece. The removed fine material particles are transported by the dielectric fluid that circulates around it. Metal removal rate and surface roughness are the two important specific measures in WEDM. The removal rate of the material (g / min) has been calculated by the difference in weight for the specimen during both machining using a high-precision equilibrium. The WEDM machining parameters for the MITUTOYO SPRINTCUT WEDM machine are shown in Table 4.

2.4. Calculation of material removal rate (mrr) and surface roughness (Ra)

The most important findings of WEDM such as the material removal rate (MRR) and Surface roughness (Ra) were considered from this investigation in order to improve specific machining parameter values. The rate of material removal has been estimated as,

Please cite this article as: P. Satishkumar, C. Saravana Murthi and R. Meenakshi, Optimization of machining parameters in wire EDM of OFHC copper using Taguchi analysis, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.06.120

Table 1
Selected Variable Levels for WEDM.

S.No	Cutting Parameters	Levels			Units
		1	2	3	
1	Pulse on time (T_{ON})	125	130	135	µ Sec
2	Pulse off time (T_{OFF})	58	56	54	µSec
3	Wire feed (WF)	10	12	14	m /min

Table 2
Taguchi's L9 Orthogonal Array.

Exp.No	Control factors and their levels		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 4
Range Values of WEDM parameters.

Parameters of WEDM	Range /Values
Discharge current	10 A
Gap voltage	20 V
T_{ON}	120–131 µs
T_{OFF}	40–50 µs
Wire Material	copper
Wire Diameter	Φ 0.25 mm
Wire Feed	70–110 m/min
Wire Tension	10 N
Ht. of Work piece	40 mm
Dielectric fluid	Deionized water

Fig. 1. WEDM Machine Setup.

$$MRR = W/T(gm/sec)$$

Where, W is the Weight of Material Removed after Machining, T is the Time in which material is removed

$$W = I - (R + w)$$

I = Initial weight of metal Specimen.
R = Remaining weight of metal specimen after Machining
w = Weight of piece which is cut from the specimen

After the workpiece was machined, surface roughness was measured upon a machining process using Surf Test 211. The surface roughness measuring tool slides across a stroke length about 0.28 mm on the workpiece with each reading.

3. Results and discussion

3.1. Influence of process parameters on MRR

Statistical software MINITAB 15 has been used in the modeling and development of experiments for the study of Taguchi and ANOVA and for the development of regression models. The analysis of process parameters using an Taguchi method enables the measurement of the impact of specific independent parameters on the quality characteristics defined. A mathematical analysis of variance (ANOVA) has been carried out. In view of the ANOVA the relation of the each parameter to change in quality attributes was assessed. The ANOVA also provides an indication of which process parameters are statistically significant. The ANOVA also specifies how each process parameters are statistically important. The test methods for MRR and Ra was used in Table 5 together with variable inputs. The grades with the primary objective are chosen from its plot and are optimized values analyzed for the particular factor.

Characteristics with maximum values reflect better machining efficiency, such as the “higher is better (HB)” removal rate in systems integration. The S/N ratio may be an accurate representation of the relevant parameter by assessing the minimum deviation. The equation for the estimation of the S/N ratio is,

“Higher is Better”(HB) S/N ratio = -10 log (1/r (1 / y12 + y22 + y32+. . .. .yn2))

The S / N machining output values for each L9 OA experiment can be determined by applying these equations.

Process parameters were analyzed from WEDM in order to assess the outcomes on MRR and Ra. The relevant results at all stages of the selected parameters are estimated and shown in Table 6. Figs. 2 and 3 indicate that the MRR is maximum at level

Table 3
Chemical Composition of Copper.

Element	Cu	Bi	Pb	Co	Sn	Cr	Mn	Si
%(weight)	99.95	0.011	<0. 01	<0.01	<0.002	0.001	0.002	0.011

Please cite this article as: P. Satishkumar, C. Saravana Murthi and R. Meenakshi, Optimization of machining parameters in wire EDM of OFHC copper using Taguchi analysis, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.06.120

Table 5
Response table for MRR and Ra.

Run	T_{ON}	T_{OFF}	WF	MRR	Ra
1	125	58	10	0.00180	1.6553
2	125	56	12	0.00227	1.8426
3	125	54	14	0.00220	1.6836
4	130	58	10	0.00231	1.8641
5	130	56	12	0.00247	2.1436
6	130	54	14	0.00268	1.6719
7	135	58	10	0.00296	2.0598
8	135	56	12	0.00311	2.2245
9	135	54	14	0.00311	2.0256

Table 6
S/N Ratio for MRR.

Level	T_{ON}	T_{OFF}	WF
1	0.002164	0.002642	0.002385
2	0.002422	0.002526	0.002551
3	0.003112	0.002467	0.002436
Delta	0.001085	0.000355	0.000158
Rank	1	2	3

3 of Ton, at level 1 of Toff and at level 2 of WF. It is evident that the maximum S/N ratio is the optimum level for each process variable. Therefore, both the mean value and the S/N ratio values suggest that the MRR is at the optimum when Ton is at level 3, Toff around level 1 & WT at stage 2, i.e. Ton at 125, Toff at 60, WT at 12.

The description of the variances of the parameters is shown in Table 7, which shows clearly that WF isn't an significant factor affecting the MRR. That is Ton (85.13 per cent) which is the most important factor for MRR preceded by Toff (9.64 per cent).

3.2. Influence of process parameters on ra

In this evaluation, the S / N ratio was selected as per the "smaller-the-better" criterion in order to reduce surface roughness. The S / N ratio for the "smaller-better" goal among all responses was determined using equation (1). In the current review, the surface roughness of WEDM were analyzed to determine the effect of WEDM input parameters. The vital influences at certain rates of the selected parameters are estimated and shown in Table 8.

The main impact for the mean and S/N ratio can be seen in the Figs. 4 and 5. Figs. 4 and 5 indicate that perhaps the Ra is lowest near to level 3 of Ton, at level 2 of Toff and at stage 3 of the WT. It is obvious that the maximum S / N ratio is the optimum level for each process measurement. Consequently, both mean and S / N ratio results illustrate that Ra is now at a minimum when Ton is at level 3, Toff at level 2 and WT at level 3, i.e. Ton at 130, Toff at 56, WT at 14.

The scanning electron microscopy (SEM) micrographs shown in Fig. 6 also highlight a same reality that the surface is marked by larger craters and wide no. of surface as well as sub-surface cracks at a higher pulse on time (125 mu) and corresponding lower pulse off time (60 mu) from Fig. 6(a) and (b). Local tensile stresses that have formed in the material due to the dielectric quenching action lead to crack formation. There are also metallic particles of waste distributed on the surface. On the other side, small craters, pock marks and tiny surface micro cracks occur at lower TON (130 mu) and higher TOFF (56 mu) from Fig. 6(c). At higher SV values, as shown in Fig. 6(d), relatively smooth surface characterized by shallow craters and also surface cracks is obtained. Rising WF from 30 to 50 would expand the distance in the spark gap. Because of the formation of shallow craters on the workpiece surface, less discharge energy is impaired on the work piece surface which decreases the surface roughness. Hence craters of a normal size are formed by conditions of discharge arising from the cumulative effects of TON, TOFF and WF . From the other extreme, as WF is less, wire is relaxed and reaches around one microscopic image on the piece of work. The frequency of the generated discharge is concentrated in one place, which limits the size of craters formed on the piece of work and thus decreases the roughness of the surface.

The study of variances of factors has been shown in Table 9 which demonstrates that Ton (64.86 per cent) is a main factor determining Ra, led by Toff (9.35 per cent) and WT (4.65 per cent).

3.3. Regression equations

Regression is a statistical method used to assess the relationship between design parameters and objectives for the aim of forecasting

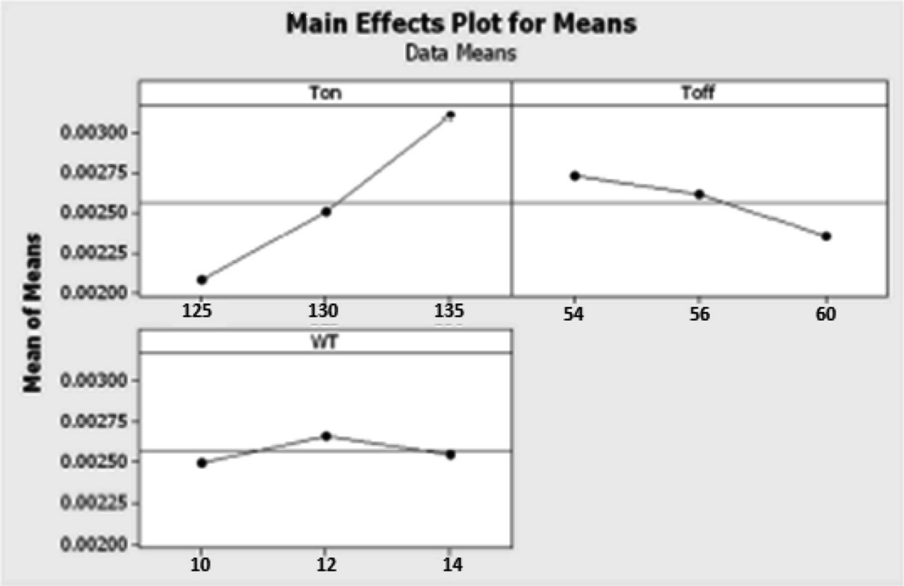

Fig. 2. Main effects plots for mean of MRR.

Please cite this article as: P. Satishkumar, C. Saravana Murthi and R. Meenakshi, Optimization of machining parameters in wire EDM of OFHC copper using Taguchi analysis, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.06.120

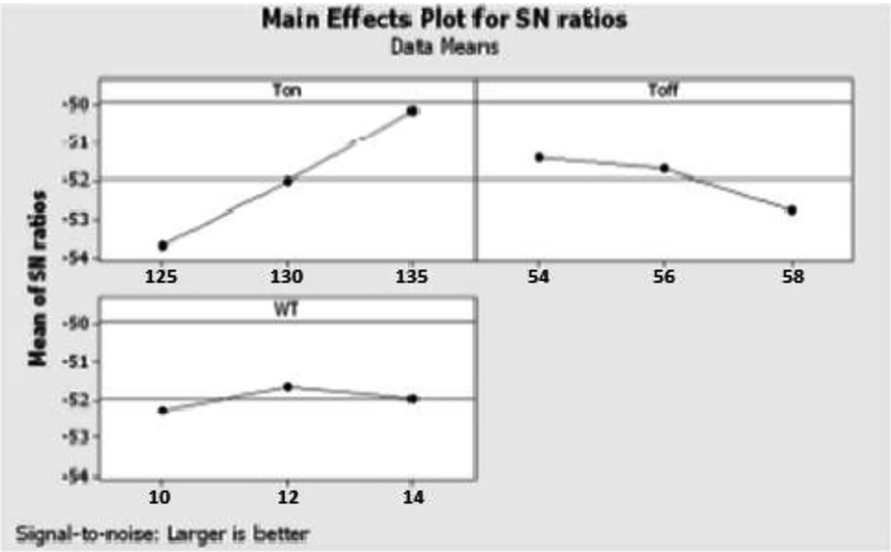

Fig. 3. Main effects plots for S/N ratio of MRR.

Table 7
Analysis of Variance for S/N ratios for MRR.

Source	DF	SeqSS	% of contribution
T_{ON}	2	0.0000014	85.13
T_{OFF}	2	0.0000003	9.64
WF	2	0.0000000	0.00
Error	2	0.0000001	5.26
Total	8	0.0000018	100

Table 8
S/N Ratio for Surface Roughness.

Level	T_{ON}	T_{OFF}	WF
1	1.612	1.811	1.837
2	1.846	2.082	1.901
3	2.116	1.871	1.978
Delta	0.363	0.225	0.114
Rank	1	2	3

effects at intermediate values and within range of a scale. Throughout this examination, the regression equations were formed between both the process variables and the responses. Nonlinear regression models have been developed derived from empirical values for evaluating MRR and Ra. The second order polynomial function is found to match the experimental results as well.

The equations obtained are the following

$$\text{Material Removal Rate (MRR)} = -7.50667E-04Ton + 0.00201317Toff + 0.000577417WT + 3.41333E-06Ton^2 + 1.81667E-05Toff^2 - 3.52917E-05WT^2 - 0.0148578 \quad R^2 = 96.24\% \tag{4}$$

$$\text{Surface Roughness (Ra)} = -0.193458\text{Ton} + 6.33994\text{Toff} - 0.0155833\text{WT} + 0.000928333\text{Ton}^2 - 0.0545104\text{Toff}^2 + 0.00258333\text{WT2} - 172.677 \quad \text{R}^2 = 98.86\% \tag{5}$$

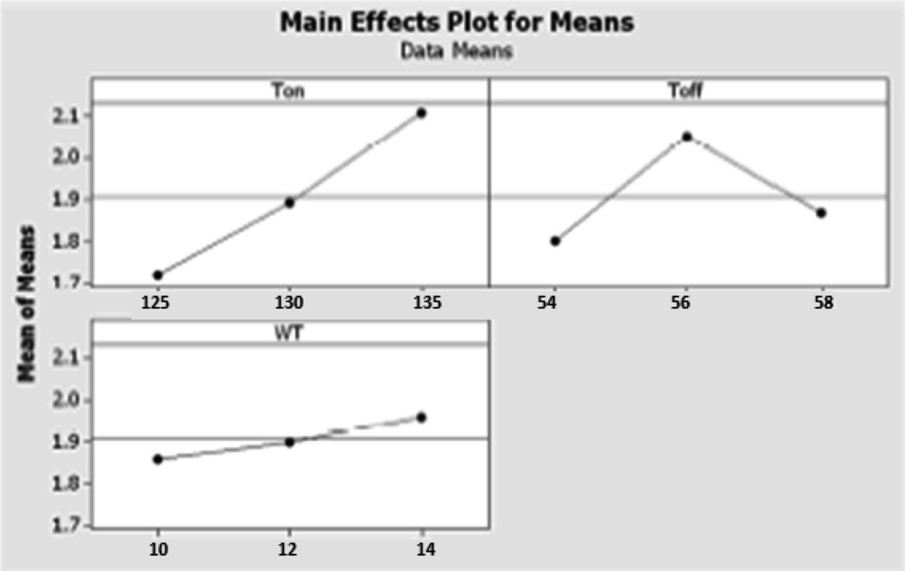

Fig. 4. Main effects plots for mean of Ra.

Please cite this article as: P. Satishkumar, C. Saravana Murthi and R. Meenakshi, Optimization of machining parameters in wire EDM of OFHC copper using Taguchi analysis, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.06.120

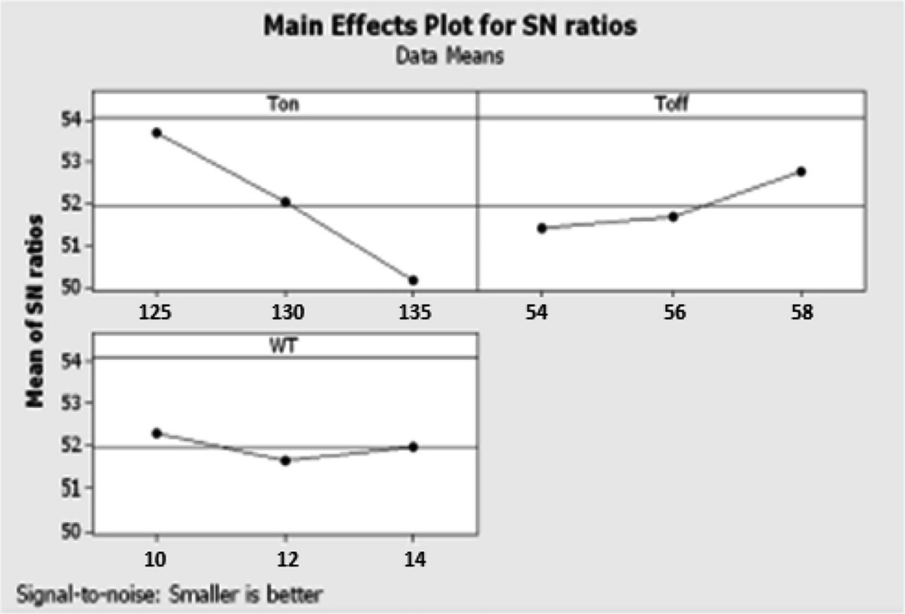

Fig. 5. Main effects plots for S/N ratio of Ra.

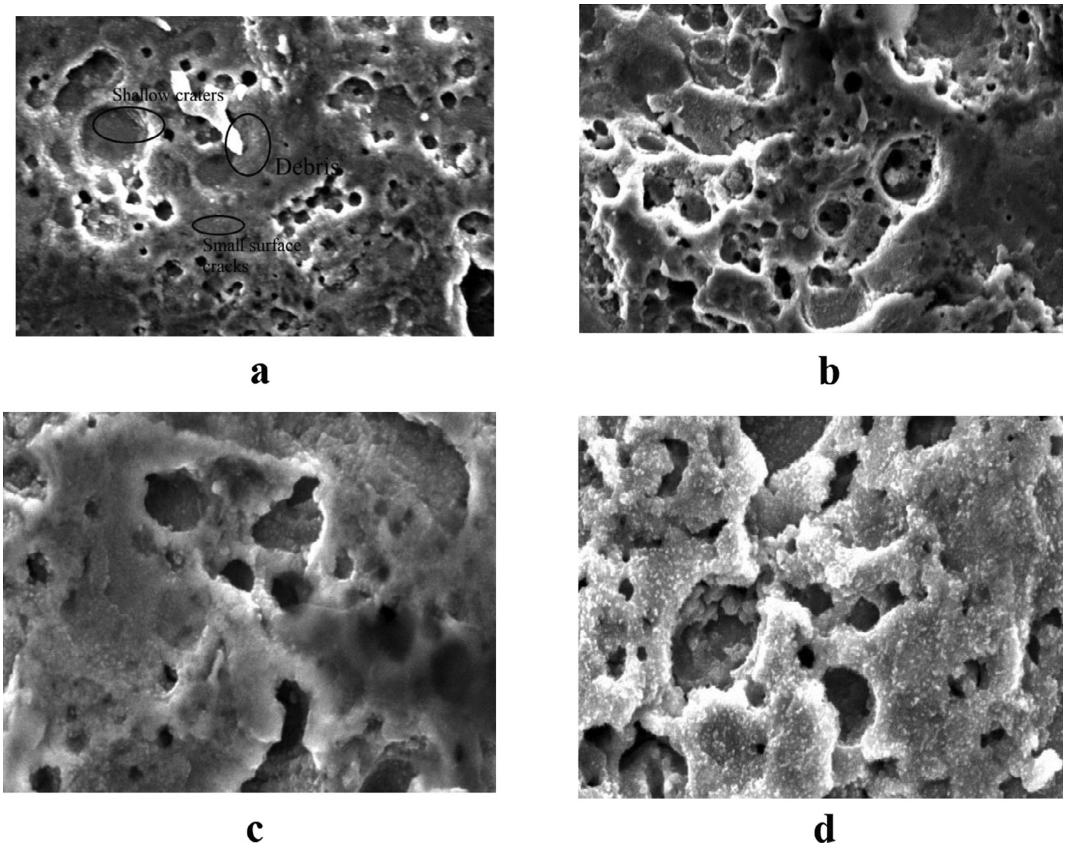

Fig. 6. (a and b) SEM micrograph at pulse on time 125 mu (TOFF = 60, WF = 10, (c) SEM micrograph at higher pulse off time 56 mu (TON = 130,WF = 12), (d) SEM micrograph at higher spark gap set voltage 50 V (TON = 135, TOFF = 54, WF = 14).

Please cite this article as: P. Satishkumar, C. Saravana Murthi and R. Meenakshi, Optimization of machining parameters in wire EDM of OFHC copper using Taguchi analysis, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.06.120

Table 9
Analysis of Variance for S/N ratios for Ra.

Source	DF	SeqSS	% of contribution
T_{ON}	2	0.213750	65.58
T_{OFF}	2	0.101502	16.11
WF	2	0.018236	4.72
Error	2	0.002868	13.59
Total	8	0.357629	100

Table 10
Results of Confirmation Test.

TON	TOFF	WF	MRR Predict	Exp.	Ra Predict	Exp.
3	1	2	0.003136	0.003456	–	–
3	2	3	–	–	2.309	2.315

3.4. Validation

Conformation tests were conducted out under the optimum process scenario to evaluate the optimum results predicted by the statistical study. The correlation of both the predicted MRR and Ra with the estimated observational data is shown in Table 10.

4. Conclusion

The results of the experiments performed on the WEDM system for the OFHC copper working material were shown below in the L9 OA trials.

- OFHC Copper has a major impact on the regulation of the values of MRR and Ra together with the WEDM machining parameters, including Pulse on, Pulse off and Wire feed.
- Wire Feed had a marginal importance for MRR and Ra values. The optimum variation of three control elements to obtain better MRR values with a modest Ra value achieved across a regression review.
- Designed regression model suggests that Ra and MRR values of OFHC copper are more comparable compared to WEDM experimental real-time performance.
- Ton at level 3 (130), Toff at level 1 (56) and WT at level 2 (8) are the optimum process parameters for MRR maximization. In the same way, the factors Ton at level 3 (130), Toff at level 2 (58) and WT at level 3 (10) are recommended for reduction of Ra. The ANOVA results suggest that Ton is the major factor influencing MRR (84.21 per cent) and Ra (64.86 per cent) followed by Toff and WF.
- Regression equations have been developed between the process variables and the responses to determine the results at moderate values within the range of the scale.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Further Reading

[1] S. Datta, S.S. Mahapatra, Modeling, simulation and parametric optimization of wire EDM process using response surface methodology coupled with grey-Taguchi technique, Int. J. Eng. Sci. Technol. 2 (2010) 162–183.

[2] H. Singh, A. Singh, Effect of Pulse On/Pulse Off Time On Machining Of AISI D3 Die Steel Using Copper And Brass Electrode In EDM, Int. J. Eng. Sci. 1 (2012) 19–22.

[3] S. Kalpakjian, S.R. Steven, Manufacturing Engineering and Technology, Pearson Education, India, 2010, p. 228.

[4] N.P. Hung, L.J. Yang, K.W. Leong, Electrical discharge machining of cast metal matrix composites, J. Mater. Process. Technol. 44 (1994) 229–236.

[5] G.F. Benedict, Electric Discharge Machining (EDM)-Nontraditional Manufacturing Processes, Marcel Dekker:, New York, Basel, 1987, p. 231 pp..

[6] G. Boothroyd, A.K. Winston, Non-Conventional Machining Processes-Fundamentals of Machining, Marcel Dekker:, New York, Basel, 1989, p. 491 pp..

[7] Yan, Biing Hwa; Tsai, Hsien Chung; Huang, Fuang Yuan; Lee, Long Chorng. Examination of wire electrical discharge machining of Al2O3p/6061Al composites. International Journal of Machine Tools & Manufacture 2005, 45 (3), 251–259.

[8] A. Pramanik, Electrical discharge machining of MMCs reinforced with very small particles, Mater. Manuf. Processes 31 (4) (2016) 397–404.

[9] S. Y. Martowibowo, A. Wahyudi, Taguchi Method Implementation in Taper Motion Wire EDM Process Optimization, Journal of The Institution of Engineers (India):Series C, Vol 93,(4), pp. 357-364, (2012).

[10] Zhang, G.; Zhang, Z.; · Ming, W.; Guo, J.; Shao, X. The multi-obj ctive optimization of medium-speed WEDM process parameters for machining SKD11 steel by the hybrid method of RSM and NSGA-II. International Journal of Advanced Manufacturing Technology 2014, 70(9–12), 2097–2109.

[11] S.S. Baraskar, S.S. Banwait, S.C. Laroiya, Multiobjective Optimization of Electrical Discharge Machining Process Using a Hybrid Method, Mater. Manuf. Processes 28 (4) (2013) 348–354.

[12] M.M. Dhobe, I.K. Chopde, C.L. Gogte, Investigations on Surface Characteristics of Heat Treated Tool Steel after Wire Electro-Discharge Machining, Mater. Manuf. Processes 28 (10) (2013) 1143–1146.

[13] P. Sivaprakasam, P. Hariharan, S. Gowri, Optimization of Micro-WEDM Process of Aluminum Matrix Composite (A413–B4C): A Response Surface Approach, Mater. Manuf. Processes 2013 (28) (July 2014) 1340–1347.

[14] T.M. Yue, Y. Dai, W.S. Lau, An Examination of Wire Electrical Discharge Machining (WEDM) of Al2O3 Particulate Reinforced Aluminum Based Composites, Mater. Manuf. Processes 11 (3) (1996) 341–350.

[15] R. Bobbili, V. Madhu, A.K. Gogia, Effect of Wire-EDM Machining Parameters on Surface Roughness and Material Removal Rate of High Strength Armor Steel, Mater. Manuf. Processes 28 (2013) 364–368.

[16] R.K. Garg, K.K. Singh, A. Anish Sachdeva, V.S. Sharma, K. Ojha, S. Singh, Review of research work in sinking EDM and WEDM on metal matrix composite materials, Int. J. Adv. Manuf. Technol. 50 (5–8) (2010) 611–624.

[17] A.K. Dhakad, J. Vimal, Multi responses optimization of wire EDM process parameters using Taguchi approach coupled with principal component analysis methodology, Int. J. Eng. Sci. Tech. 9 (2) (2017) 61–74.

[18] A.S. Gill, S. Kumar, Investigation of micro-hardness in electrical discharge alloying of En31 tool steel with Cu–W powder metallurgy electrode, Arab. J. Sci. Eng. 43 (3) (2018) 1499–1510.

[19] R. Kataria, J. Kumar, B.S. Pabla, Experimental investigation and optimization of machining characteristics in ultrasonic machining of WC-Co composite using GRA method, Mater. Manuf. Process. 31 (5) (2016) 685–693.

[20] T. Thankachan, K. Soorya Prakash, M. Loganathan, WEDM process parameter optimization of FSPed copper-BN composites, Mater. Manuf. Process. 33 (3) (2018) 350–358.

[21] X. Hanjie, R. Dalin, W. Shibo, EDM machining quality control and parameters optimization, Int. J. Adv. Manuf. Technol. 89 (5–8) (2017) 1307–1315.

[22] A. Dey, K.M. Pandey, Selection of optimal processing condition during WEDM of compocasted AA6061/cenosphere AMCs based on grey-based hybrid approach, Mater. Manuf. Processes 1 (10) (2018) 1549–1558.

[23] R. Ramakrishnan, L. Karunamoorthy, Modeling and multi-response optimization of Inconel 718 on machining of CNC WEDM process, J. Mater. Process. Technol. 207 (1–3) (2008) 343–349.

[24] A. Varun, N. Venkaiah, Simultaneous optimization of WEDM responses using grey relational analysis coupled with genetic algorithm while machining EN 353, Int. J. Adv. Manuf. Technol. 76 (1–4) (2014) 675–690.

[25] S.K. Garg, A. Manna, A. Jain, An Investigation on Machinability of Al/10 % ZrO2 (P)-Metal Matrix Composite by WEDM and Parametric Optimization Using Desirability Function Approach, Arab. J. Sci. Eng. 39 (4) (2014) 3251–3270.

[26] Satishkumar, D.; M. Kanthababu, M.; V. Vajjiravelu, V.; Anburaj, R.; Thirumalai Sundarrajan, N.; Arul, H. Investigation of wire electrical discharge machining characteristics of Al6063/SiCp composites. International Journal of Advanced Manufacturing Technology 2011, 56(9–12), 975–986.

[27] J.K. Katiyar, A.K. Sharma, B. Pandey, Synthesis of iron-copper alloy using electrical discharge machining, Mater. Manuf. Processes 33 (14) (2018) 1531–1538.

[28] K. Jangra, S. Grover, A. Aggarwal, Optimization of multi machining characteristics in WEDM of WC-5.3% Co composite using integrated approach of Taguchi, GRA and Entropy method, Front Mech Eng. 7 (3) (2012) 288–299.

[29] P.M. Kumar, K. Sivakumar, N. Jayakumar, Multiobjective optimization and analysis of copper–titanium diboride electrode in EDM of monel 400™ alloy, Mater. Manuf. Processes 33 (13) (2018) 1429–1437.

[30] M.K. Kulekci, A. Akkurt, U. Esme, I. Ozkul, Multiple regression modeling and prediction of the surface roughness in the Wedm process, Mater. Technol. 48 (1) (2014) 9–14.

[31] R.V. Rao, D.P. Rai, J. Balic, A multi-objective algorithm for optimization of modern machining processes, Eng. Appl. Artif. Intell. 61 (2017) 103–125.

Please cite this article as: P. Satishkumar, C. Saravana Murthi and R. Meenakshi, Optimization of machining parameters in wire EDM of OFHC copper using Taguchi analysis, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2020.06.120